# LOW CONTACT-FORCE AND COMPLIANT MEMS PROBE CARD UTILIZING FRITTING CONTACT

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## ABSTRACT

We present a new MEMS probe card made of electroplated Ni micro-cantilevers, which has compliant structures, and uses a kind of electric breakdown, or fritting, to make electric contacts to electrodes on ICs. The characteristics of fritting contact between Ni probe and Al electrodes were investigated, and Ni was found to have lower contact resistance than other materials. A micro-machining process for the probe cards, including deposition of layers having different internal stress to make a protruding cantilever shape, was developed.

## INTRODUCTION

MEMS probe cards have some advantages over conventional needle probe cards. Because MEMS probe cards are micro-fabricated on Si wafers, they can be applied to higher pad-density chips, and can be effective in high-frequency testing. Moreover, if actuators are integrated in each probe of a MEMS probe card, it gains further advantages, such as compensation of probe-pad distance deviation [1], and direct switching of the probe-pad contacts [2].

The critical problem of the micromachined probe cards is that each probe can not endure or produce the force required to break oxide on metal pad surface. A force of over 100 mN is necessary to make a contact to Al electrodes, which are most widely used for I/O pads of ICs. A cantilever type MEMS probe card developed by Zhang et al.[1] can not produce contact force larger than 1 mN and the probes can only contact to pads without oxidized surface such as gold pads. Some groups have developed MEMS probes which can make contact with Al pads. They used stiffer structures than cantilevers, as membranes on micro-cavity [3] or bridges with both sides clamped[4]. However these structures can not be downsized with keeping compliance and large contact force.

A contact method with low contact force is a key to realize a MEMS probe card with independent compliance. In addition, a low contact-force method is suitable for low damage probing and for probe cards with more than ten thousand probes. We have focused on fritting phenomena [5], and have investigated the characteristics of fritting contacts[2,6,7].

In order to utilize fritting process for breakdown of Al pads on ICs, the probe card must have a 'double probe' structure, as shown in Fig. 1, to avoid damages on IC devices by fritting current [8]. Each pad is touched by two probes and the voltage is applied to cause a breakdown. After breakdown, the 'dummy probe' is switched off and the signal probe is used for testing. Additionally, a direct testing of contact itself can be done using this double probes.

In this paper, we will present a micromachied cantilever type MEMS probe card designed to use a low-force contact utilizing fritting.

## FRITTING PROCESS

We have measured the characteristics of fritting process for application to MEMS probe cards. Fig. 2 shows a diagram of the apparatus used for the measurement of fritting characteristics. The needle probe is driven by piezoelectric stage forward and backward to the Al sample on the electric balance. The contact force is controlled to a constant value between 10 μN and 1 mN by accuracy of 10 μN. The voltage and the current applied to the contact were measured by the ammeter and voltmeter, while the transient change is measured by AD converters that are connected to point A-A' and B-B' in Fig. 2. Fig. 3 shows a typical example of changes in voltage and current when a fritting occurs. An electric breakdown happens and current starts to flow when the applied voltage reaches to the fritting voltage. Then, the current limiter starts and current decreases to 100 mA. After the breakdown, the current is set to 1 mA and the contact resistance is measured.
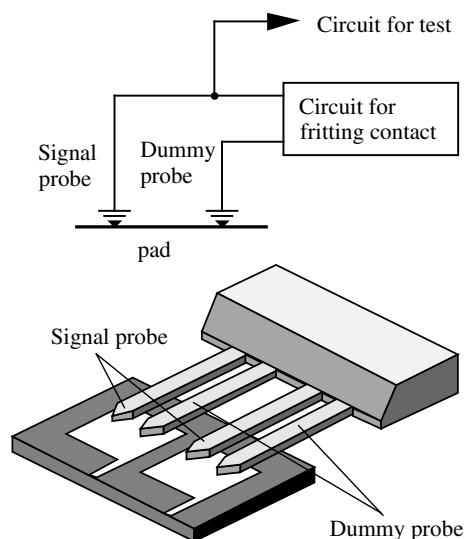
Fig. 1 Illustration of MEMS probe card utilizing fritting contact which has 'double probe' structure.
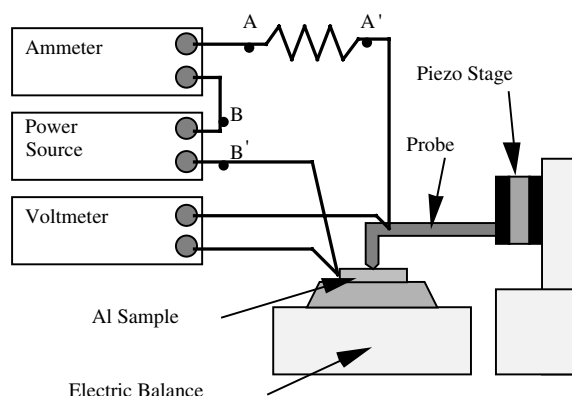


Fig. 2 Experimental setup for measuring the fritting characteristics of needle probes and Al electrodes. Analog digital converters are connected to A-A' and B-B' to measure the transient change in current and voltage respectively.
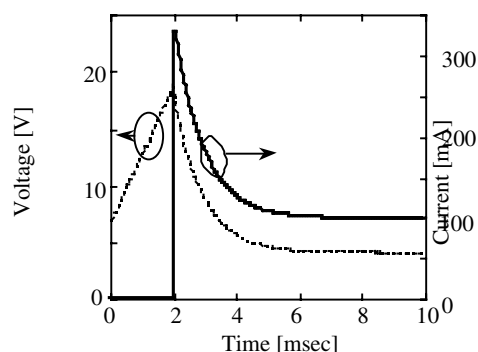


Fig. 3 Transient change in the current and the voltage when a fritting occurs between a Ni electroplated needle probe and an Al electrode.
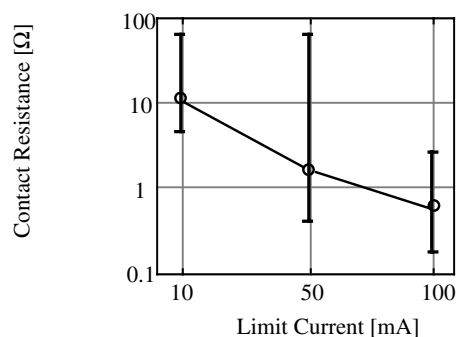


Fig. 4 Relationship between the limit current and the contact resistance for Ni coated W probe.
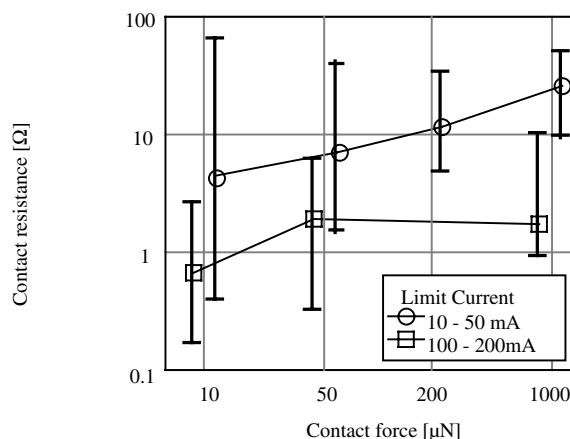


Fig. 5 Relationship between the contact force and the contact resistance for Ni coated W probe.

Fig. 4 shows the relationship between the limit current and contact resistance of Ni probe. The contact resistance decreases as the current limit becomes large because the heat generated by the current enlarges the contact area. Fig 5 shows the influences of the contact force on the contact resistance. The average values and the deviation ranges are indicated for the contact forces of 10, 50, 200 and 1000 μN. When the limit current is small, the deviation range increases as the contact force becomes smaller. On the other hand, when the limit current is large, the contact resistance is smaller and deviation range is constantly small. These results indicate that the contact becomes unstable as the contact force decreases at smaller limit current, and that large current is necessary to obtain stable and low contact resistance. Table 1 shows the contact resistance of probes coated by various metals. A Ni electroplated probe can realize low contact resistance compared to other probe materials.

Table 1: Contact resistance between Al electrode and needle probes coated with various materials (Current limit is 100 mA, and contact force is 50 $\mu$N for W, 10 $\mu$N for Ni, W, Be and Pd)

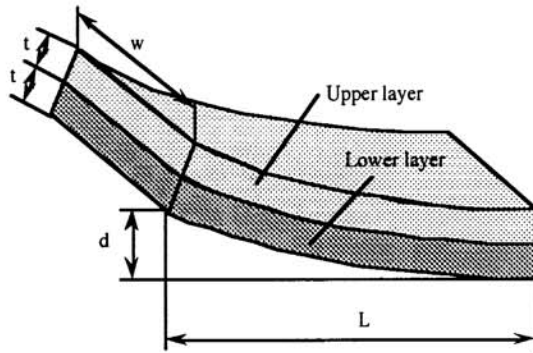| Probe coating | Contact resistance |
|---|---|
| Ni | 0.64 $\Omega$ |
| W | 0.84 $\Omega$ |
| BeCu | 0.97 $\Omega$ |
| Pd | 4.1 $\Omega$ |



Fig. 6 Cantilever which has two layers of different internal stress.



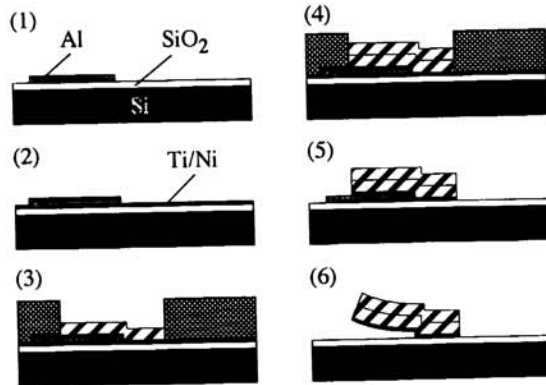Fig. 7 Fabrication process for microcantilevers. (1) Sputter and IBE Al on SiO2. (2) Sputter Ti/Ni as seed for electroplating. (3) Pattern photoresist and electroplate low-stress Ni. (4) Electroplate high-stress Ni. (5) Remove Resist and sputtered Ti/Ni. (6) Etch Al sacrificial layer by KOH solution

## MICROCANTILEVER DESIGN

For the structure material of the compliant MEMS probe card, we used electroplated Ni, because it has relatively large Young's modulus and strain limit, and a thick films

can easily be deposited with low costs, and also, Ni is a good material for making contact using fritting process as described in the previous section. To make a contact with pads on the devices, the cantilevers should be protruding from the surface of the probe card. A protruding cantilever can be made by bending a cantilever outward the surface as shown in Fig. 6. We made this structure by controlling the internal stress of successively deposited layers of electroplated Ni. The internal stress of Ni electroplated layer can be controlled by changing the plating bath, current density, pH, and temperature.

The deflection $d$ and the spring constant $k$ of a cantilever which has two layers of different internal stress, as shown in Fig. 6, are given by

$$d = 3 L^2 (T_1 - T_2) / (8 E t) \qquad (1)$$
$$k = 2 E w t^3 / L^3 \qquad (2)$$

where $E$, $L$, $w$, and $t$ are Young's modulus, the length, width, and the thickness of each layer, respectively. $T_1$ and $T_2$ are the internal stress in the upper and lower layers. The total deflection of the lever $d$ should be used to apply the contact force ($d_f$) and to compensate the distance deviation ($d_c$). Then,

$$d = d_f + d_c$$

If we assume that $d_f = d_c = 10$ $\mu$m, and the contact force is 10 $\mu$N, the spring constant should be 1 N/m. The stress in a Ni film electroplated in sulfamic acid bath can be changed from 0 to 200 MPa, and that in Watts bath can be changed from 100 to 400 MPa [9]. Here, we assume the difference of the internal stresses of each layer ($T_1 - T_2$) is 200 MPa, and width $w = 40$ $\mu$m. Using these conditions and equations (1) and (2), we obtain $L = 212$, and $t = 0.84$ $\mu$m. ($E = 200$ GPa [10].).

Table 2 Electroplating conditions. (Tempreture: 60°C)

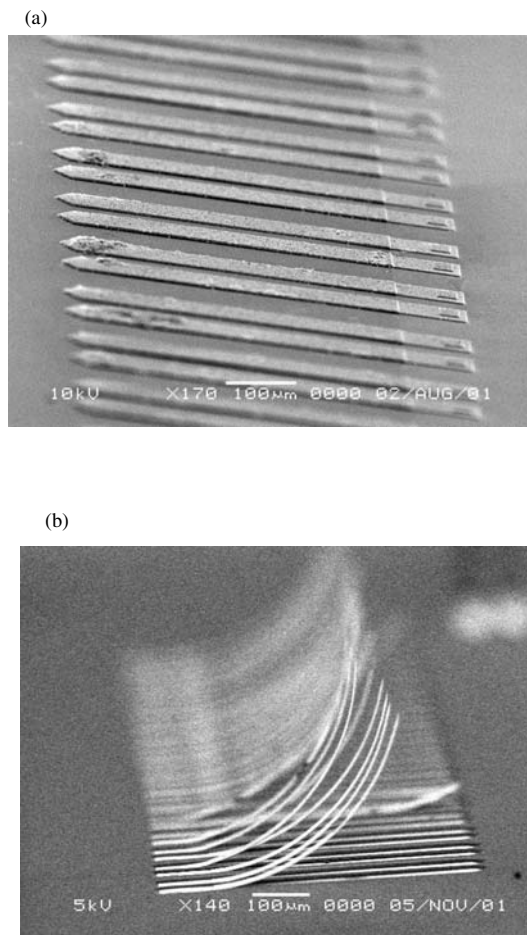| | Layer | Bath | Current Density [mA/mm²] | Time [sec] |
|---|---|---|---|---|
| (a) | (1) Lower | Sulfamic acid | 0.5 | 120 |
| | (2) Upper | Sulfamic acid | 1.5 | 40 |
| (b) | (1) Lower | Sulfamic acid | 0.1 | 580 |
| | (2) Upper | Watts | 1.0 | 30 |

(a)



(b)



Fig. 8 SEM images of microcantilevers fabricated using conditions (a) and (b) in Table 2.

## FABRICATION

A fabrication process for cantilevers consisted of layers of different internal stress as shown in Fig 7. A Ni layer with smaller stress is electroplated before that with larger stress (Fig. 7 (3) and (4)). Table 2 shows the electroplating conditions used for fabrication of the micro-probes. In the condition (a), the current density is changed and plating bath is changed for the condition (b). Fig. 8 (a) and (b) shows the SEM images of fabrication results for conditions (a) and (b). In the condition (b), the cantilever tip was not observed to raise as estimated. This is influences of sputtered Ti/Ni layers which may have large internal stress. In condition (b), cantilevers stood up during the electroplating process. That is because the internal stress in the Ni layer plated in Watts bath is so large that the electroplated layer was peeled off.

The calculated value of the stress $(T_1 - T_2)$ is approximately 200 MPa, which is much larger than the expected value and enables better design of the cantilever with larger deflecion. The influences of the stress of the layer plated in Watts bath can be decreased by increasing the thickness of lower layer (sulfamic acid bath) and decreasing the upper layer.

## CONCLUSION

We present a MEMS probe which has compliant structures, and utilize fritting to make electric contacts to IC pads with low contact force. The characteristics of fritting contact between Ni probe and Al electrodes were investigated, and Ni was found to have lower contact resistance than other materials. A micro-machining process for the probe cards, including deposition of Ni layers having different internal stress to make a protruding cantilever shape, was developed. The Watts bath and sulfamic acid bath was found to have enough internal stress difference to make sufficient deflection of microcantilevers.

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